Hardware Activities

(1)	Build Model
(2)	Perform Modal Tests
(4)	Measure Plant Transfer Functions
(6)	Design & Implement Compensator
(8)	Measure Closed Loop Performance
(10)	Compare Measured & Predicted Closed Loop Performance

Modeling Activities

(1)	Build Model
(3)	Update Model Parameters
(5)	Update Model Parameters
(7)	Model Compensator
(9)	Predict Closed Loop Performance

Legend

- = Validation Steps
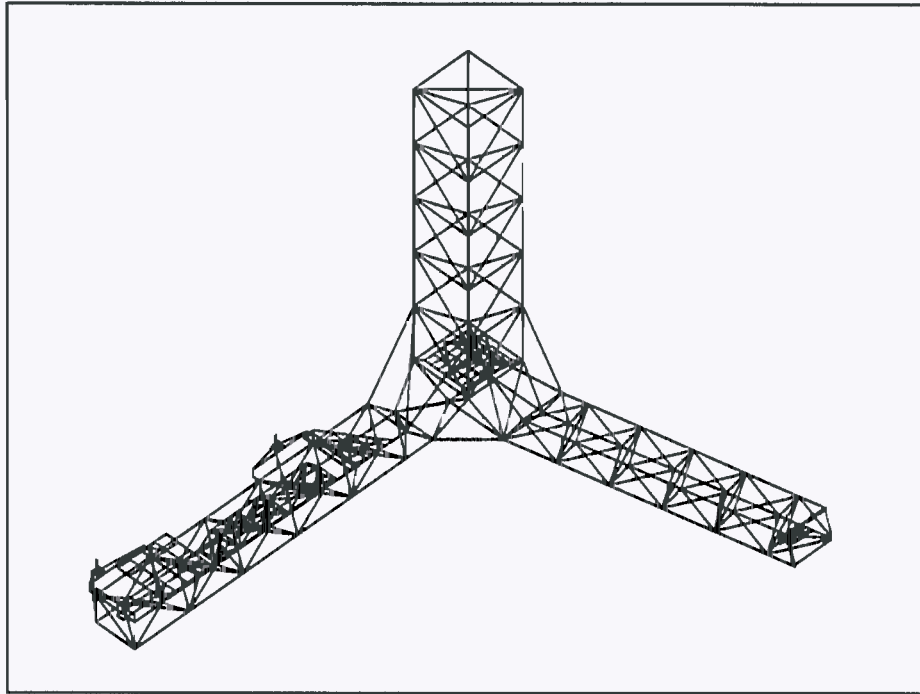- = Methodology Steps
- = Support Steps

Finite Element Geometry

- Structural model specified in IMOS.

- Structural model consists of plate, beam, truss, and rigid body elements (RBEs).

- 2,577 total dofs: 1,832 independent w.r.t. multi-point constraints

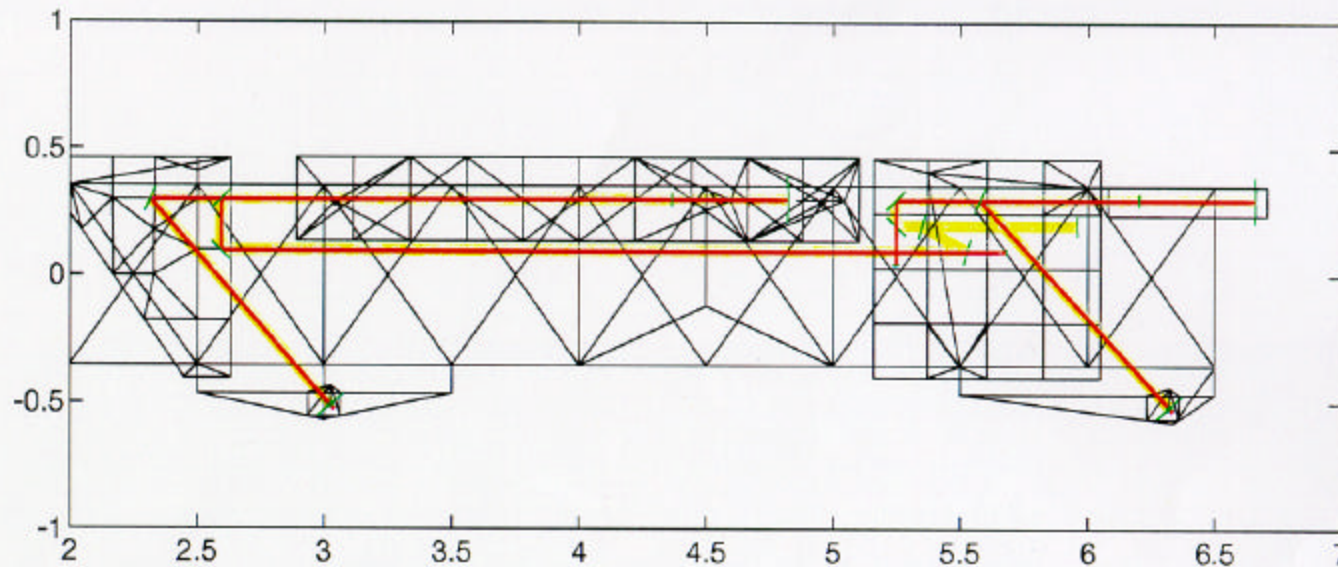- **Experimentally determined element properties** consistent with validation of modeling *methodology*.

- Finite element description ($d \in R^{2577}$):

$$M\ddot{d} + Kd = B_f f$$

- Incorporation of multi-point constraints from RBEs ($d_n \in R^{1832}$):

$$d = \begin{bmatrix} d_n \\ d_m \end{bmatrix} = G d_n \quad \Rightarrow \quad M_{nn}\ddot{d}_n + K_{nn} d_n = B_{nf} f$$

Ray Trace of Optical Prescription w/ FE Geometry

- Optical prescription specifies shapes, positions, and orientations of optical elements.

- Prescription is specified in IMOS relative to the structural model, thereby easing model integration.

- Analytic differential ray trace (COMP) yields linear optical perturbation model:
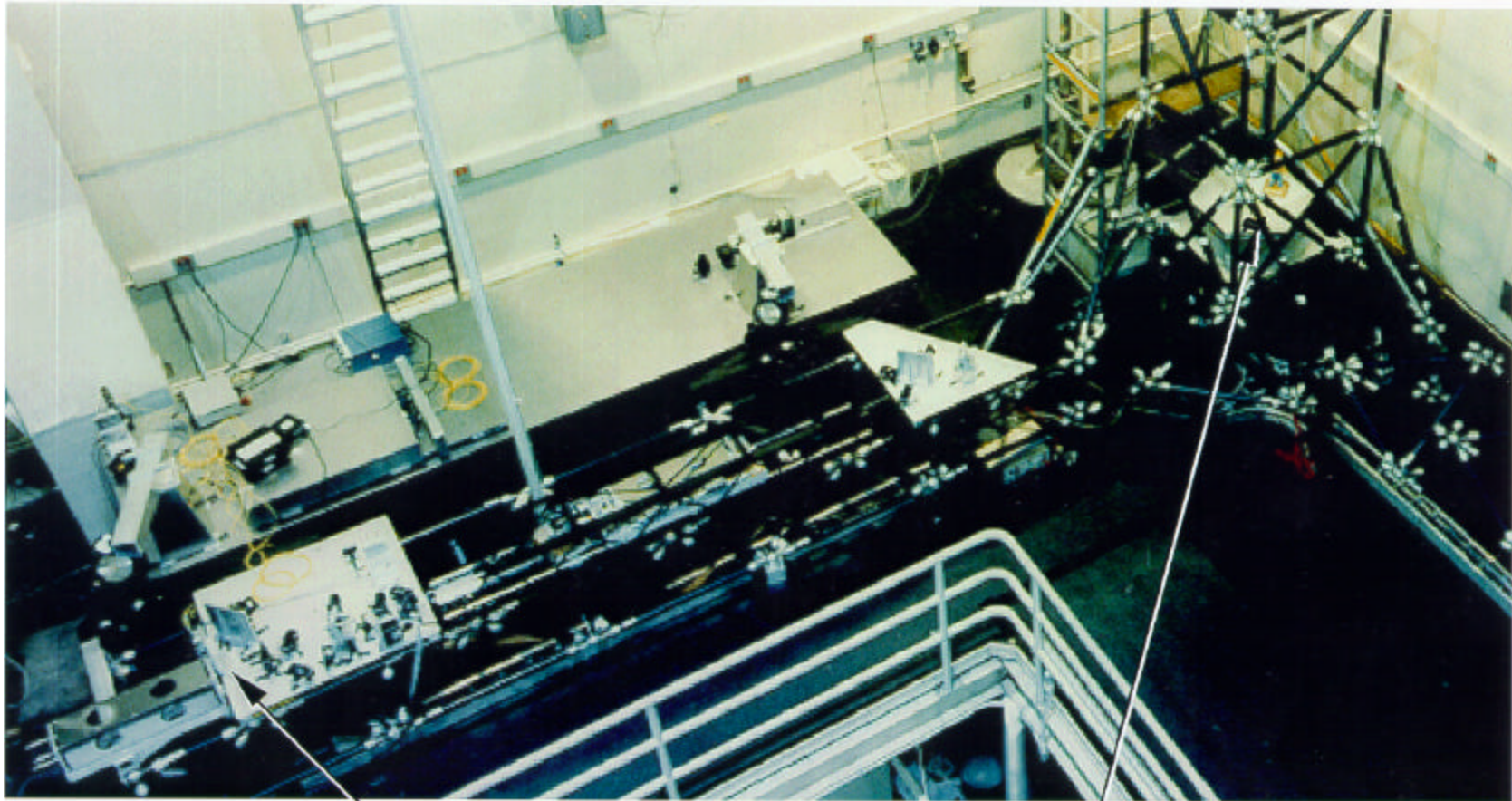
$$y_{opt} = C_{opt}\, d$$

Measured/Predicted Voice Coil Plant Transfer Function
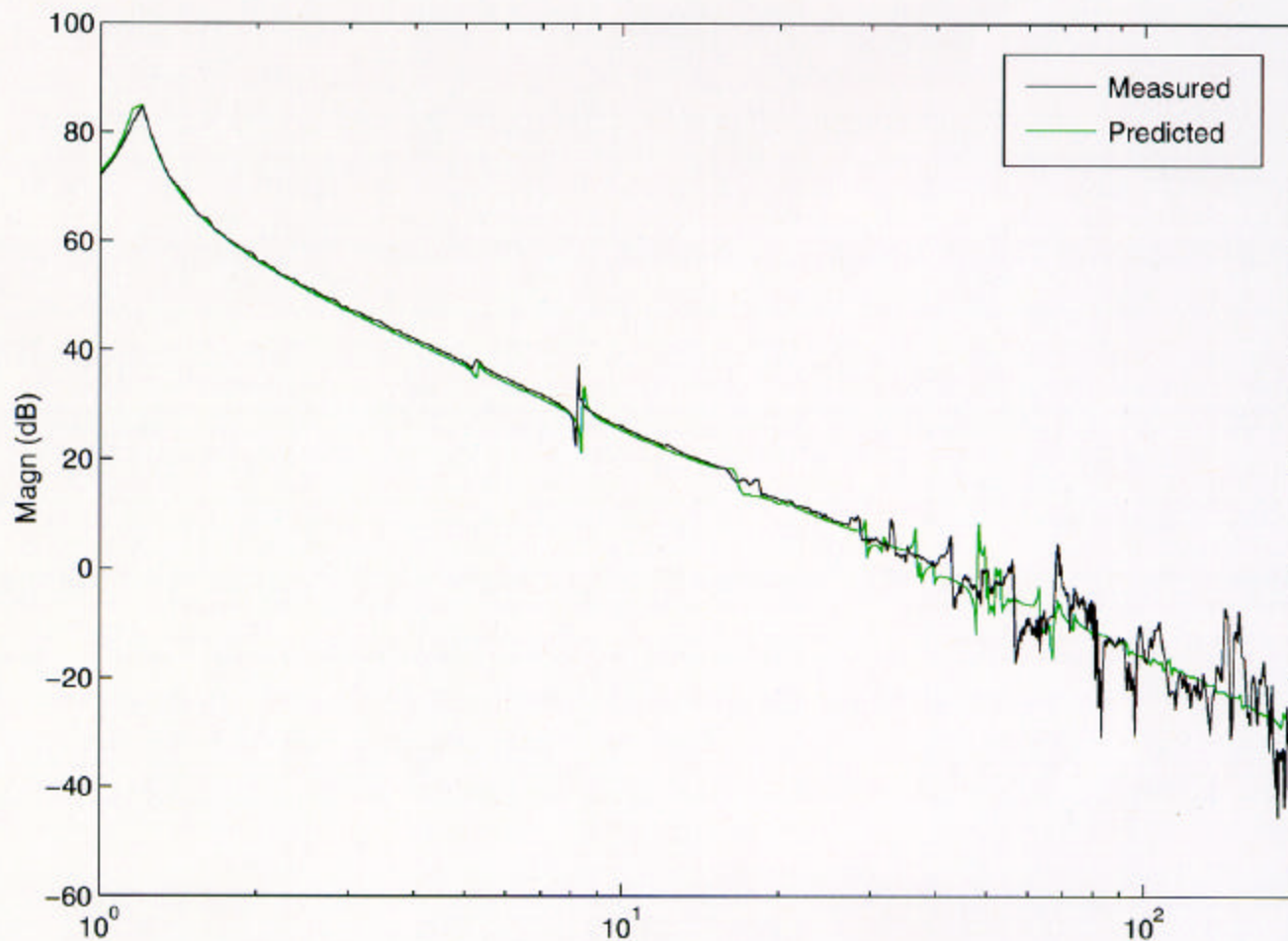
MPI Testbed Transfer Function Measurement

FRINGE
DETECTOR
OUTPUT

INPUT
DISTURBANCE
SOURCE

- Typically, disturbance has broadband PSD, $\Phi_d(\omega)$, and the performance measure is OPD variation, σ_{opd} :

$$\sigma_{opd}^2 \;=\; \frac{1}{\pi} \int_0^\infty |G(\jmath\omega)|^2\, \Phi_d(\omega)\, d\omega$$

- Generally, an accuracy of a **factor of two** in σ_{opd} is desired.

- Use a bandlimited white noise disturbance to characterize the accuracy of the predicted transfer functions in the frequency range of interest ($[\omega_1, \omega_2]$):

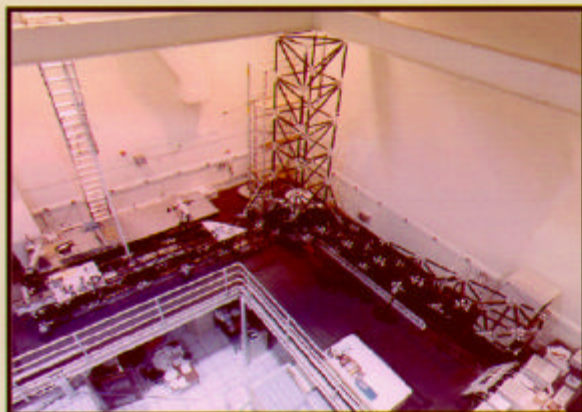$$\sigma_g^2 \;=\; \frac{1}{\pi} \int_{\omega_1}^{\omega_2} |G(\jmath\omega)|^2\, d\omega$$

- Apply the factor of two desirement to the ratio of σ_g for the predicted and measured transfer functions:
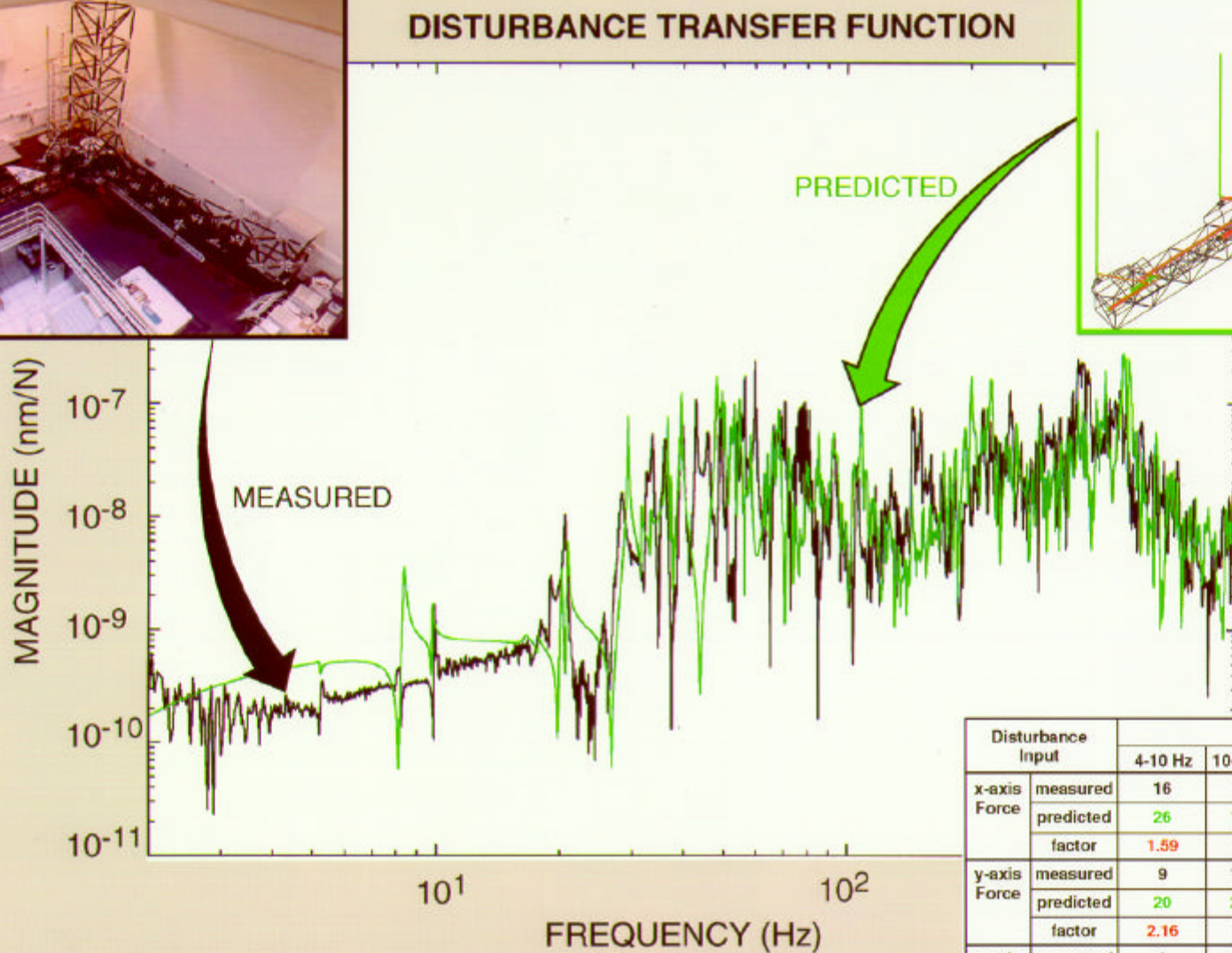
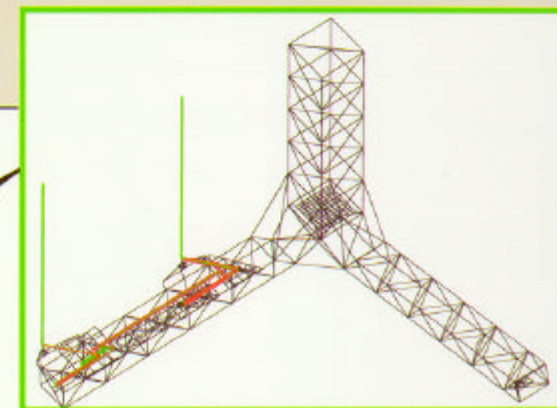$$\frac{1}{2} \leq \frac{\sigma_{gp}}{\sigma_{gm}} \leq 2$$

INTEGRATED MODELING OF OPTICAL SYSTEMS (IMOS): CLOSED LOOP MODELING METHODOLOGY VALIDATION

MPI TESTBED

MPI IMOS MODEL

DISTURBANCE TRANSFER FUNCTION

PREDICTED

MEASURED

Disturbance Input		σ_g			
		4-10 Hz	10-100 Hz	100-900 Hz	4-900 Hz
x-axis Force	measured	16	723	6,329	6,370
	predicted	26	1,167	2,485	2,746
	factor	1.59	1.61	0.39	0.43
y-axis Force	measured	9	1,025	6,750	6,827
	predicted	20	2,158	2,799	3,535
	factor	2.16	2.11	0.41	0.52
z-axis Force	measured	3	1,028	4,746	4,856
	predicted	7	888	4,576	4,759
	factor	2.58	0.86	0.99	0.98

PREDICTION ACCURACY BY DIRECTION & FREQUENCY

mar19 MPI Z-Force FRF: V0.0 (red); HIFI (green) ;Measured (black)